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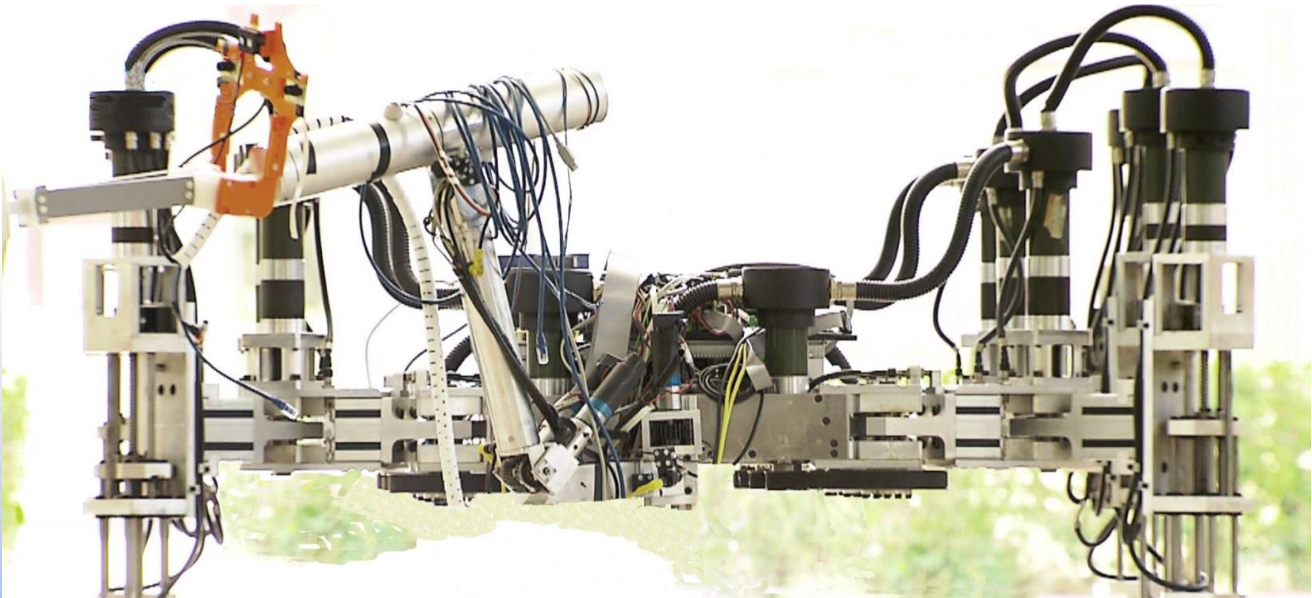

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CHAPTER 32

MULTIPLE ROBOTS, SINGLE OPERATOR: CONSIDERATIONS ABOUT INFORMATION AND COMMANDING

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Multiple robot, single operator scenarios suppose a challenge in terms of human factors. Two relevant issues are keeping the situational awareness and managing the workload of operators. In order to address these problems, this work analyses the management of information and commands in multi-robot missions. About the information, this paper proposes a selection based on mission and operator states. Regarding the commands, this work reflects about the levels of automation and the methods of commanding.

1 Introduction

In recent years, multi-robot missions have been applied in multiple areas. The teams of robots may be homogeneous or heterogeneous and include ground, marine, submarine or aerial robots. The arguments that support the use of multiple robots are diverse: e.g. to cover larger areas, to reduce the duration of mission or to perform simultaneous tasks.

Robot fleets present obvious advantages over single robots. First of all, they have a wider range of application, since they can carry out complex missions that require coordinated tasks. Additionally, they can perform missions more efficiently because they have multiple resources to properly assign to the tasks. Previous works quantify these advantages in terms of targets reached and time consumed (Garzón, 2015).

Nevertheless, multi-robot missions pose a series of challenges related to human factors (Cummings, 2008). The main ones are keeping the situational awareness and managing the workload of operators. Currently, the operators have to do an effort to perceive information, understand the mission, make decisions and control the robots.

This paper analyses the management of information and commands in multi-robot missions, in order to address the mentioned human factors problems.

2 Multi-robot missions

Multi-robot missions can be addressed as complex systems or various single robot missions (Roldán, 2015). In the first perspective, the mission is a set of resources that are assigned to a series of tasks to achieve a set of objectives. In the second one, the mission is a set of tasks that are simultaneously performed by single robots and consist of sequences of actions.

A review of the multi-robot scenarios covered by the literature leads to the tasks collected in table 1. Most of the missions can be split into these basic tasks. For instance, fire detection and extinguishing is a sequence of begin, surveillance (to find the fires), reconnaissance (to check them), capture (for taking the water), release (for throwing it) and finish tasks.

Table 1. Tasks of multi-robot missions.

Task	Description
Begin	Preparation and deployment
Surveillance	Covering area to detect targets
Reconnaissance	Visiting points to check targets
Tracking	Following mobile targets
Capture	Picking a resource
Release	Placing a resource
Maintenance	Performing maintenance operations
Finish	Collection and shutdown

Other important issue about multi-robot missions is the control and coordination architecture (Roldán, 2016). This architecture determines the roles of operator, interface and fleet and the communication among them. There are three paradigms: centralized (mission planning, task allocation and path planning are performed by the control station), distributed (these functions are performed by the robot fleet) and hybrid (compromise between centralized and distributed).

3 Information

Multi-robot missions generate huge amounts of data: e.g. robot telemetry, payload data, resources, targets, camera images... This volume of data depends on the number of robots and may exceed the attention span of operator. For this reason, the interface must search the relevant information within the whole data. As seen in Fig. 1, the proposal of this work is selecting the information according to mission and operator states.

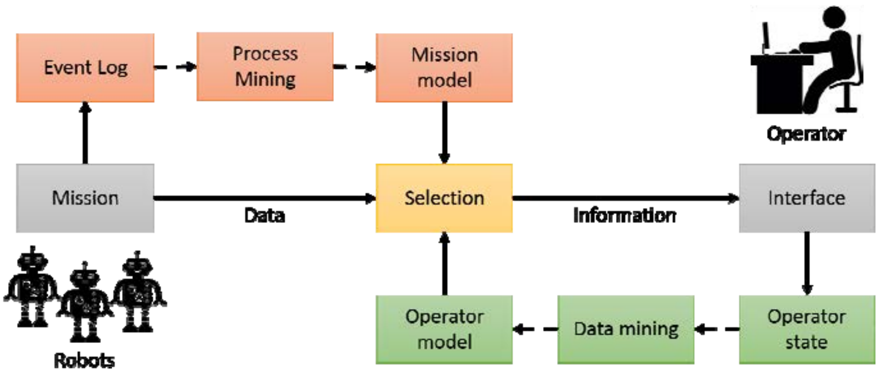

Fig. 1. Selection of information.

3.1 Selection according to the mission state

This selection of information requires a mission model to determine its state and describe its evolution. This model can be obtained by means of mission analysis or through the experience of previous similar missions.

Process mining (Van Der Aalst, 2011) is an emerging discipline that allows automatic discovery of process models through event logs. An example of application of this discipline in the context of multi-robot missions is shown in Fig. 2.

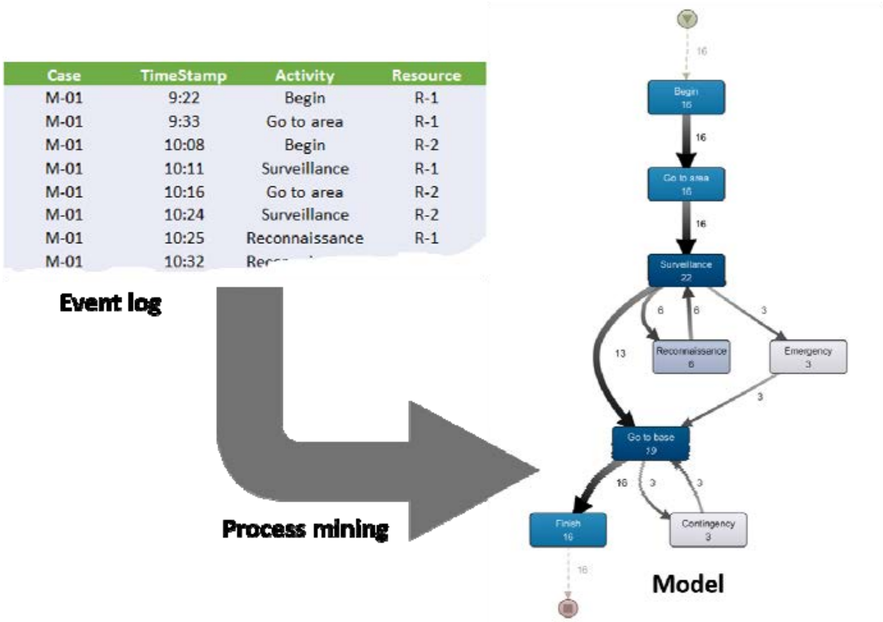

Fig. 2. Process mining applied to multi-robot mission.

3.2 Selection according to operator

This selection of information uses an operator model to predict his behavior during the mission. This model has to integrate operator state and preferences and can be obtained by means of data mining.

In this way, the information should be adapted to the physical and psychological state of operator. For instance, when the operator is stressed, tired or bored, the system should reduce the amount of data, in order to prevent saturation and errors.

In addition, the information should be adapted to the preferences of the operator. For example, if the operator usually asks for a specific information in a certain moment of the mission, the interface should anticipate the operator request and provide him with this information.

4 Commanding

Commanding is the other relevant issue for multi-robot missions. Choosing the correct commanding method can lead to save time and reduce errors. In this sense, two relevant issues are the level of automation and the kind of commands.

4.1 Level of automation

(Beer, 2014) recapitulates the literature about levels of automation; from the ten levels defined by (Sheridan, 1979) to the four levels proposed more recently by (Ruff, 2002) and other authors. This last case is considered simpler and more useful, so it is shown in table 2 and explained below.

Table 2. Levels of automation.

Number	Name
1	Full manual control
2	Management by consent
3	Management by exception
4	Full automatic control

In the first level, the operator selects and launches the tasks and the role of computer is restricted to support. The second level is management by consent, which means that the computer selects the action and the operator accepts or rejects them. The third level is management by exception, where the computer selects the tasks and launches them if the operator does not cancel them. In the fourth level, the computer selects and launches the tasks and the role of operator is limited to supervision.

A question widely discussed in literature is “which is the best level of automation?” A consensus answer is that it depends on multiple factors, such as the specific mission, fleet and operator. For instance, (Parasuraman, 2000) distinguishes among different functions (information acquisition, information analysis, task selection and execution) and proposes the use of different levels of automation for each of them.

4.2 Method of commanding

If the level of autonomy is full automatic control, defining a method of commanding is not required. This is because the computer makes decisions and executes actions and the operator does not have to manage them. Nevertheless, if the level of autonomy is management by exception, management by consent and, specially, full manual control, choosing an adequate method of commanding is relevant. In fact, it has influence not only on the time required for sending the commands but also on the performance of control and monitoring.

This section addresses the methods of commanding in low autonomies systems (levels between 1 and 2). In these modes, the operator creates and controls the tasks and the computer only shows the possibilities or suggests one or more of them.

The lowest level is the direct control of the robots to perform the tasks. In this case, the operator uses a device to command the robots (e.g. keyboard, mouse, joystick, joypad or remote control). This control is based on speed commands of translation (x, y and z axis) and rotation (roll, pitch and yaw). This method has the restriction that the operator only commands a robot at time, remaining the rest as not used.

The next method is the definition of path through waypoints. In this case, the operator sends goals to the robots that they have to reach. These waypoints contain at least the target position and orientation, but also can include information such as speed, time, and actions to be performed when reached. There are two ways to define the waypoints: doing path planning before mission, and generating each waypoint when the previous one is reached. This method allows the operator to move multiple robots at the same time, but it still require an effort to command and supervise them.

In the highest level, the operator directly sends the tasks to the robots. Therefore, the robots have to split the high level tasks into low level actions. An example is shown in Fig. 3, where the operator commands the surveillance of an area and the robot generates the coverage path and follows the waypoints.

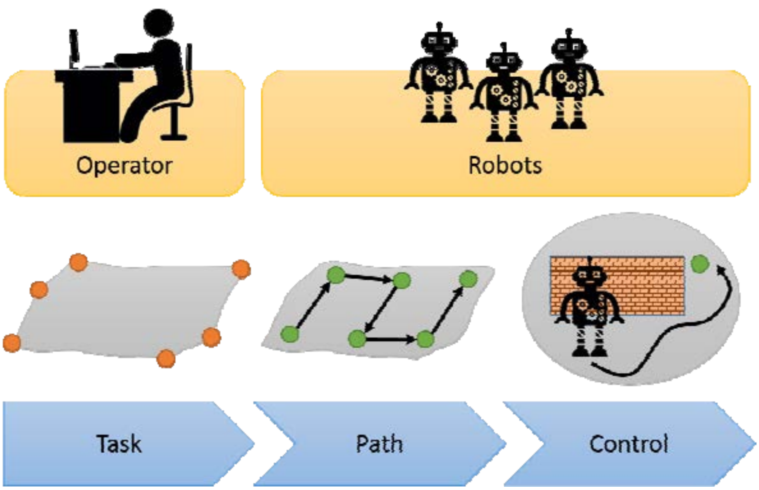

Fig. 3. High-level commanding.

The structure of these task commands is explained in table 3. The station and robot fields define the sender and receiver of command respectively. Task field determines the task: e.g. surveillance, reconnaissance, tracking, etc. Point list can contain not only one or more points but also an area defined by its vertices. Finally, target and resource lists define respectively the goals and the means of the task (e.g. in fire detection and extinguishing, the target is the fire and the resource is the water).

Table 3. Command structure.

Name	Description
Station	Station that sends the command.
Robot	Robot that must receive the command.
Task	Name of the task.
Point list	Area, path or point of the task.
Resource list	Resources of the task
Target list	Objectives of the task.

5 Conclusions

This paper analyses the multiple robot, single operator scenarios. These systems present challenges related to human factors, such as the situational awareness and the workload of operators. On the one hand, this paper proposes a selection of information based on mission and operator states. On the other hand, it proposes the use of high-level commands from the operator to the robots.

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